PROCESS MONITORING ON AFPT PILOT PLANT BY USING STATISTICAL PROCESS CONTROL

MOHAMED AFIZAL BIN MOHAMED AMIN

A report submitted in partial fulfillment of
the requirements for the award of the degree of
Bachelor of Chemical Engineering

Faculty of Chemical Engineering and Natural, Resources
Universiti Malaysia Pahang

MAY 2009

"I declare that this thesis entitled *"Process Monitoring On AFPT Pilot Plant by Using Statistical Process Control"* is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree"

Signature : ……………………………………….

Name : Mohamed Afizal Bin Mohamed Amin

Date : 2 May 2009

In The Name of Allah, Most Gracious, Most Merciful

I dedicate to:
my beloved family members,
my friends,
those who has lend their effort

ACKNOLEDGMENT

First and foremost, I would like to take this opportunity to thank my respectful supervisor Miss Fathie Bt. Ahmad Zakil who has given his guidance, constructive idea, valuables advice and extended support throughout my research. Special thank to my former supervisor En Noor Asma Fazli B. Abdul Samad, the one who has blaze the idea about this research. My special thank also to the lecturer from other faculties especially lecturer from Faculty of Electric and Electronic Engineering and Faculty of Science and Technology Industry who has give magnificent effort as well as their precious time to share their knowledge during this time. I am really impressed for what they have done.

I also would like to thank my co-supervisor Miss Syahida who has given a lot of idea and guidance. Without his idea, maybe the path to achieve the objective of this research will become harder. I am really appreciated for his effort. My appreciation also extended to my fellow friend for their encouragement and positives influence.

To my family, especially my parents, who has give an extended effort and encouragement throughout my education these several years. I am very grateful and only Allah can repay their efforts and kindness. May Allah bless all of you and me.

ABSTRACT

Statistical Process Control (SPC) technique has been widely develops for fault detection, diagnosis and control tool. Today, the industries have to keep sustainable production and operate as fault free as possible because faults that present in a process operation increase the operating cost due to products with undesired specifications, malfunction of plant equipment and instrumentation. Therefore, this study is conducted to introduce Statistical Process Control method for detecting fault early enough, so that the corrective action can be taken before the process is upset or out of control. For this research, the historical data at normal operating condition is collected by using Air Flow Pressure Temperature (AFPT) Pilot Plant. The generate data then will be ensure distribute normally before further analysis is carried out. Shewhart individual chart and Shewhart range chart are use to facilitate the fault detected. Based on the result, the Shewhart individual capabilities is more precise estimate of the process standard deviation compare to Shewhart range because it has a smaller uncertainty. Besides that, the computation of Shewhart individual involves all the measurements in each sample, while the computation of Shewhart range involves only two measurements (the largest and the smallest). Based on the result obtained, it shows that both Shewhart range and Shewhart individual chart, can detect fault for both process variables (Temperature and Pressure) and quality variables (Density). After the correlation coefficient is determined it show that the gap between UCL and LCL with CL become wider and make the usage of this technique in Shewhart chart for fault detection gives the best for it has the highest fault detection efficiency.

ABSTRAK

Kaedah Proses Kawalan Statistik (SPC) digunakan secara meluas untuk membangunkan satu sistem yang diguna pakai untuk mengesan dan mengenalpasti punca kesilapan. Kebanyakan industri berlumba-lumba untuk mengekalkan kualiti hasil keluaran dan pada masa yang sama mengelakkan kesilapan dalam proses daripada berlaku. Kesilapan yang berlaku boleh menyebabkan peningakatan dari segi kos operasi disebabkan terhasilnya produk yang tidak melepasi piawaian yang dikehendaki. Oleh itu, kajian ini dijalankan untuk memperkenalkan kaedah Proses Kawalan Statistik bagi mengesan kesilapan lebih awal supaya punca kesilapan yang berlaku boleh diperbetulkan sebelum proses berada diluar kawalan. Untuk kajian ini, data daripada proses yang lalu dihasilkan pada keadaan operasi yang normal. Selepas itu, data yang tertabur secara normal dipilih daripada data yang dihasilkan sebelum carta kawalan dihasilkan. Skop kajian ini meggunakan carta individu Shewhart (Shewhart Individual) dan carta julat Shewhart (Shewhart Range) untuk mengesan kesilapan. Daripada hasil kajian, didapati setiap carta mempunyai kemampuan yang berlainan. Carta Individu Shewhart lebih persis dalam mentaksir proses dengan menggunakan deviasi piawaian berbanding dengan carta julat Shewhart kerana mempunyai nilai ketidakpastian yang rendah. Selain daripada itu, pengiraan dalam carta Individu Shewhart melibatkan semua sukatan dalam setiap sampel, manakala carta Julat Shewhart hanya melibatkan dua sukatan dalam setiap sampel (data maksimum dan data minimum). Hasil daripada kajian, didapati carta Individu Shewhart dan carta Julat Shewhart boleh mengenalpasti kesilapan yang berlaku dalam pembolehubah proses iaitu tekanan dan suhu dan pembolehubah kualiti iaitu densiti. Selepas pekali korelasi ditentukan, didapati juga selang diantara UCL dan LCL dengan CL menjadi lebih besar. Carta kawalan yang baru ini mampu untuk mengenalpasti lebih banyak kesilapan disebabkan selang yang lebih lebar. Oleh itu, penggunaan teknik ini dalam carta Shewhart untuk mengenalpasti kesilapan merupakan kaedah yang terbaik disebabkan keefektifannya.

TABLE OF CONTENTS

CHAPTER	TITLE	PAGE
	TITLE PAGE	**i**
	DECLARATION	**ii**
	DEDICATION	**iii**
	ACKNOWLEDGMENT	**iv**
	ABSTRACT	**v**
	ABSTRAK	**vi**
	TABLE OF CONTENTS	**vii**
	LIST OF TABLES	**ix**
	LIST OF FIGURES	**x**
	LIST OF SYMBOLS	**xi**
	LIST OF ABBREVIATIONS	**xii**
	LIST OF APPENDICES	**xiii**
1.	**INTRODUCTION**	
	1.1. Research Background	1
	1.2. Objective of the Research	2
	1.3. Scope of Research	3
	1.4. Rationale and Significance	3
2	**LITERATURE REVIEW**	
	2.1 Process Monitoring	5
	2.2 Statistical Process Control	6
	2.3 Definitions of Fault, Fault Detection and Fault Diagnosis	7
	2.4 Normal Distribution	9
	2.5 Control Chart	10

	2.5.1	The S-Chart	11
	2.5.2	The R-Chart	11
	2.5.3	The $\bar{X}$ Control Chart	12
	2.6	Correlation Coefficient	15
	2.7	Outlier	16
3	**METHODOLOGY**		
	3.0	Introduction	17
	3.1.	Variable Selection for Process Monitoring	17
	3.2.	Normal Operating Condition (NOC) Data Selection	18
	3.3.	Correlation Coefficients	19
	3.4	Control Limit for Control Chart	20
	3.4.1	The Individual Shewhart Chart	20
	3.4.2	The Shewhart Range Chart	21
	3.5	Generated Out of Control, OC data	22
	3.6	A Procedure to Establish Shewhart Individual and Shewhart	23
	3.7	Summary of Research Methodology	24
4	**RESULTS AND DISCUSSIONS**		
	4.1	Normal Operating Condition Data	25
	4.2	Normal Distribution	27
	4.3	Control Chart	28
	4.4	Correlation Coefficient	34
	4.5	Improved Statistical Process Control	35
5.	**CONCLUSION AND RECOMMENDATION**		
	5.1	Conclusion	36
	5.2	Recommendation	37
	LIST OF REFERENCES		38
	APPENDIX A		40
	APPENDIX B		42

LIST OF TABLES

TABLE NO.	TITLE	PAGE
3.1	Factors for Calculating Limits for $\bar{X}$ and R Charts	22
4.1	Summarizing of Correlation Coefficient	34
4.2	The Contol Limit For Improved Chart	34

LIST OF FIGURES

FIGURE NO.	TITLE	PAGE
1.1	Statistical Process Control	l2
2.1	Probabilities Associated With Normal Distribution.(Montomery & Runger ,2003)	10
2.2	Example of Xbar (R) Chart And Xbar (S) Chart	12
2.3	Example of Control Chart	14
4.1	Process Variable for Pressure, Temperature and Density	26
4.2	Histogram Plot of NOC Data for Temperature (a), Pressure (b) and Density (c)	27
4.3	Shewhart Range and Shewhart Individual Chart During Normal Condition	28
4.4	Shewhart Range and Shewhart Individual Chart for Temperature During Faulty Condition	30
4.5	Shewhart Range and Shewhart Individual Chart for Pressure During Normal Condition	31
4.6	Shewhart Range and Shewhart Individual Chart for Pressure During Faulty Condition	31
4.7	Shewhart Range and Shewhart Individual Chart for Density During Normal Condition	32
4.8	Shewhart Range and Shewhart Individual Chart for Density During Faulty Condition	33
4.9	Improved Control Chart for Temperature Variable and Pressure Variable	35
A.1	AFPT Pilot Plant Process Control Training System	40
A.2	Distributed Control System (DCS)	41

LIST OF SYMBOLS

μ	-	Mean
σ^2	-	Variance
σ	-	Standard Deviation
Z	-	Standard Form
P	-	Probability
B_i	-	Control Chart Constant
$\bar{s}$	-	Mean of the subgroup Standard Deviation
n	-	Number of Data
$\bar{\bar{x}}$	-	Average of the subgroup mean
c_{ij}	-	Correlation Coefficient

LIST OF ABBREVIATIONS

AFPT	-	Air Flow Pressure Temperature
CL	-	Center Line
FDD	-	Fault Detected and Diagnosis
LCL	-	Lower Control Limit
NOC	-	Normal Operating Condition
OC	-	Out of Control
PCA	-	Principal Component Analysis
PCorrA	-	Partial Correlation Coefficient
SPC	-	Statistical Process Control
UCL	-	Upper Control Limit

LIST OF APPENDICES

APPENDIX	TITLE	PAGE
A	AFPT Pilot Plant	40
B	Raw Data	42

CHAPTER 1

INTRODUCTION

1.1. Research Background

Industry technologies in chemical field are facing a lot of challenges. The industries have to keep sustainable production and at the same time increase or maintain within specified limits the quality specifications of the products. In addition, the whole production process has to operate at the minimum production of waste, minimum consumption of utilities, minimum cost of re-work and re-processing. To achieve these targets, an alternative approach in chemical process has to initiate in order to detect and diagnose fault. Chemicals plants need to operate as fault free as possible because faults that present in a chemical process operation increase the operating cost due to products with undesired specifications, malfunction of plant equipment and instrumentation. More extremely serious are a gross accident such as explosion and fire. Venkat, et al.,(2003) mentioned that the petrochemical industry annually losses approximately $20 billion due to poor management in abnormal detections events. Chen, et al., (2004) also highlighted that the US-based petrochemical industry could save up to $10 billion annually if abnormal process behavior could be detected, diagnosed and appropriate dealt with. Therefore, monitoring strategy for early fault detection and diagnosis is extremely important not only from a production cost and the quality product viewpoints, but also for the safety in a process.

Purpose of this research is to build up Statistical Process Control (SPC) using historical data of processes in order to develop fault detection, diagnosis and control tool. Statistical Process Control (SPC) can be applied to software development processes. A process has one or more outputs, as show in Figure 1. These outputs have measurable attributes or behaviors. SPC is based on the idea that these attributes have two sources of variation which natural (also known as common) and assignable (also known as special) causes. If the observed variability of the attributes of a process is within the range of variability from natural causes, the process is said to be under statistical control. When that variability exceeds the range to be expected from natural causes, one then identifies and corrects assignable causes.

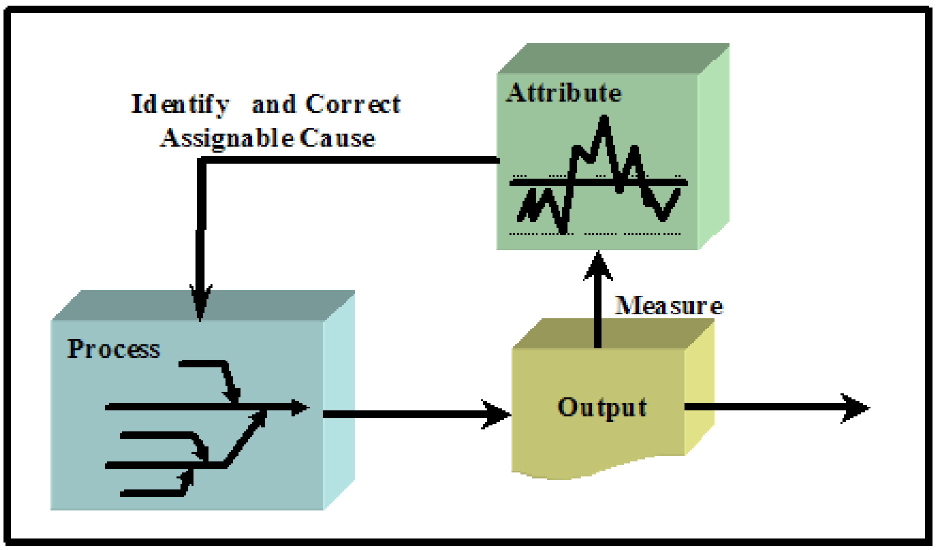

Figure 1.1 Statistical Process Control

1.2. Objective of the Research

To develop control system identification using Statistical Process Control in order to detect abnormal situations early enough so that corrective action can be taken before the process is seriously upset and out of control.

1.3. Scope of the Research

There are several scope of study highlighted in this research in order to achieve the objectives:

1. An Air Flow Pressure Temperature AFPT pilot plant is used as a case study.
2. The behavior of the process is monitoring in order to perform fault detected and diagnosis FDD for the process operation. This can be done by development of Statistical Process Control SPC based on Air Flow Pressure Temperature AFPT pilot plant dynamic behavior
3. Selection of process variables of interest and key process variables:
   - Gas temperature and pressure are chosen as the process variables of interest
   - Key quality variable selected is process variable that are highly correlated with two selected quality variables of interest. The selected key process variable is gas density.

4 The correlation coefficient is develop between the quality variable(s) and the process variable(s)

5 Developing set of data at Normal Operation Condition (NOC) and Out of Control (OC) by using AFPT Pilot Plant simulation

6 The Shewhart Individual and Shewhart Range Chart are developed

7 The faulty condition is incorporated into the process in order to see the performance of the control chart to detect fault(s) .

1.4. Rationale and Significance

SPC chart is the most technically sophisticated tool to monitor and correlate the performance of any given process. The major benefit of this approach is that there is no need for a fundamental or causal model of the system. In chemical processes, data based approaches have been widely used for process monitoring, because it is often difficult to develop detailed physical model (Kano, et al., 2000). In manufacturing, the primary focus of control charts is to bring the process back into control. In software, the product is also a focus. When a software process exceeds the control limits, rework is typically performed on the product. In manufacturing, the cost of stopping a process is high. In software, the cost of stopping is lower, and few shutdown and startup activities are needed (Jalote and Saxena, 2002). Control chart cannot control a process parameter, but it was a powerful diagnostic tool to see if the process upset. It can be used to change the process when fault occur but not the most efficient way to control process in real time. This approach only needs a good data collected from the simulation and the models should be quickly and easily perform.

CHAPTER 2

LITERATURE REVIEW

2.1 Process Monitoring

In chemical industrial plant, production process variables must be maintained within specified limits in order to ensure the plant operate properly. Distribution of key variables beyond these limits can have significant consequences for plant safety, product quality and plant profitability. Process monitoring plays a key role in ensuring that the plant performance satisfies the operating objectives. Generally, there are three highlighted objectives in process monitoring which are:

1. Routine Monitoring.

   To ensure that process variables are within specified limits.

2. Detection and Diagnosis.

   To detect an abnormal process operation and diagnose it root cause

3. Preventive Monitoring.

   To detect an abnormal situations early enough in order to take corrective action before the process is out of control.

The traditional approach for process monitoring is used to monitor and verify that the process remains in specified limits. This limit checking technique is a standard feature of computer control systems and is widely used to validate measurements of process variables such as flow rate, temperature, pressure, and liquid level. Process variables are measured quite frequently with sampling periods that typically are much smaller than the process settling time. However, for most industrial plants, many important quality variables cannot be measured on-line. Instead, samples of the product are taken on an infrequent basis (e.g., hourly or daily) and sent to the quality control laboratory for analysis. (Seborg *et. al.,* 2004).

2.2 Statistical Process Control, SPC

Statistical Process Control (SPC) is an effective method of monitoring a process through the use of control charts. Kourti and MacGregor, (1996) mentioned that the objective of performing Statistical Process Control is to monitor the process over time in order to detect any unusual events allowing quality and process improvement and it is essential to be able to track the cause of an Out of Control (OC) signal. In order to ensure that process is operating at normal operating condition as required, faults must be detected, diagnosed and removed. These activities, and their management, are called as Statistical Process Control, SPC (Miletic *et al*., 2004). The major objective in SPC is to use process data and statistical techniques to determine whether the process operation is normal or abnormal. The SPC methodology is based on the fundamental assumption that normal process operation can be characterized by random variations about a mean value. If this situation exists, the process is said to be in a state of statistical control (or in control), and the control chart measurements tend to be normally distributed about the mean value. By contrast, frequent control chart violations would indicate abnormal process behavior or an out-of-control situation.

Statistical process control (SPC) involves using statistical techniques to measure and analyze the attribute in processes. Most often used for manufacturing processes, the intent of SPC is to monitor product quality and maintain processes to fixed targets. By collecting data from samples at various points within the process, variations in the process that may affect the quality of the end product or service can be detected and corrected. SPC only requires a good database of normal historical data, and the models of case study are quickly and easily build from this. SPC does not control the process but rather performs a monitoring function and gives signals for corrective action in the form of identification and removal the root cause of the process abnormal behaviors. No matter how good or bad the design, SPC can ensure that the product is being manufactured as designed and intended. Thus, SPC will not improve a poorly designed product's reliability, but can be used to maintain the consistency of how the product is made and, therefore, of the manufactured product itself and its as-designed reliability. In contrast, SPC use statistical tools to observe the performance of the production process in order to predict significant deviations that may later result in rejected product. Apart from that, SPC also indicates when no action should be taken instead of action that should be taken in a process if an abnormal event occurs. Then, a search would be initiated to attempt to identify the root cause of the abnormal behavior. The root cause is referred to as assignable cause or the special cause while the normal process variability is referred to as common cause or chance cause.

2.3 Definitions of Fault, Fault Detection and Fault Diagnosis

Generally, fault is deviations from the normal operating behavior in the process that are not due to disturbance change or set point change in the process. In other words fault in the process refers to degradation between 100% performance and complete failure. Himmelblau (1978) mentioned that the term fault is generally defined as a departure from an acceptable range of an observed variable or a calculated parameter associated with a process. This defines a fault as a process abnormality or symptom, such as high temperature in a reactor or low product quality and so on. The underlying causes of this abnormality, such as a failed coolant pump or a controller, are called the basic events or the root causes. The basic event is also referred to as a malfunction or a failure. Faults can be categorized into the following categories (Gertler, 1998):

1. Additive process faults

   Unknown inputs acting on the plant, which are normally zero. They cause a change in the plant outputs independent of the known input. Such fault can be best described as plant leaks and load.

2. Multiplicative process faults

   These are gradual or abrupt changes in some plant parameters. They cause changes in the plant outputs, which also depend on the magnitude of the known inputs. Such faults can be best described as the deterioration of plant equipment, such as surface contamination, clogging, or the partial or total loss of power.

3. Sensor faults

   These are discrepancies between the measured and actual values of individual plant variables. These faults are usually considered additive (independent of the measured magnitude), though some sensor faults (such as sticking or complete failure) may be better characterized as multiplicative.

4. Actuator faults

   These are discrepancies between the input command of an actuator and its actual output. Actuator faults are usually handled as additive though, some kind (such as sticking or complete failure) may be described as multiplicative.

Fault detection is a monitoring process to determine the occurrence of an abnormal event in a process, whereas fault diagnosis is to identify its reason or sources. The detection performance is characterized by a number of important and quantifiable benchmarks namely:

1. Fault sensitivity
   The ability of the technique to detect faults of reasonably small size.

2. Reaction speed
   The ability of the technique to detect faults with reasonably small delay after their occurrence.

3. Robustness
   The ability of the technique to operate in the presence of noise, disturbances and modeling errors, with few false alarms.

2.4 Normal Distribution

Normal distribution plays a central role in SPC. The normal distribution is also known as the Gaussian distribution. Suppose that a random variable x has a normal distribution with a mean μ and a variance σ^2 denoted by $N(\mu, \sigma^2)$. The probability that x has a value between two arbitrary constant, a and b, is given by

$$P(a < x < b) = \int_a^b f(x)dx \tag{2.1}$$

Where $f(x)$ is the probability density function for the normal distribution:

$$f(x) = \frac{1}{\sigma\sqrt{2\pi}} exp\left[-\frac{(x-\mu)^2}{2\sigma^2}\right] \tag{2.2}$$

Where,

$$Z = \frac{X-\mu}{\sigma}$$

The following probability statements are valid for the normal distribution (Montgomery & Runger, 2003),

$$P(\mu - \sigma < x < \mu + \sigma) = 0.6827$$

$$P(\mu - 2\sigma < x < \mu + 2\sigma) = 0.9545$$

$$P(\mu - 3\sigma < x < \mu + 3\sigma) = 0.9973 \tag{2.3}$$

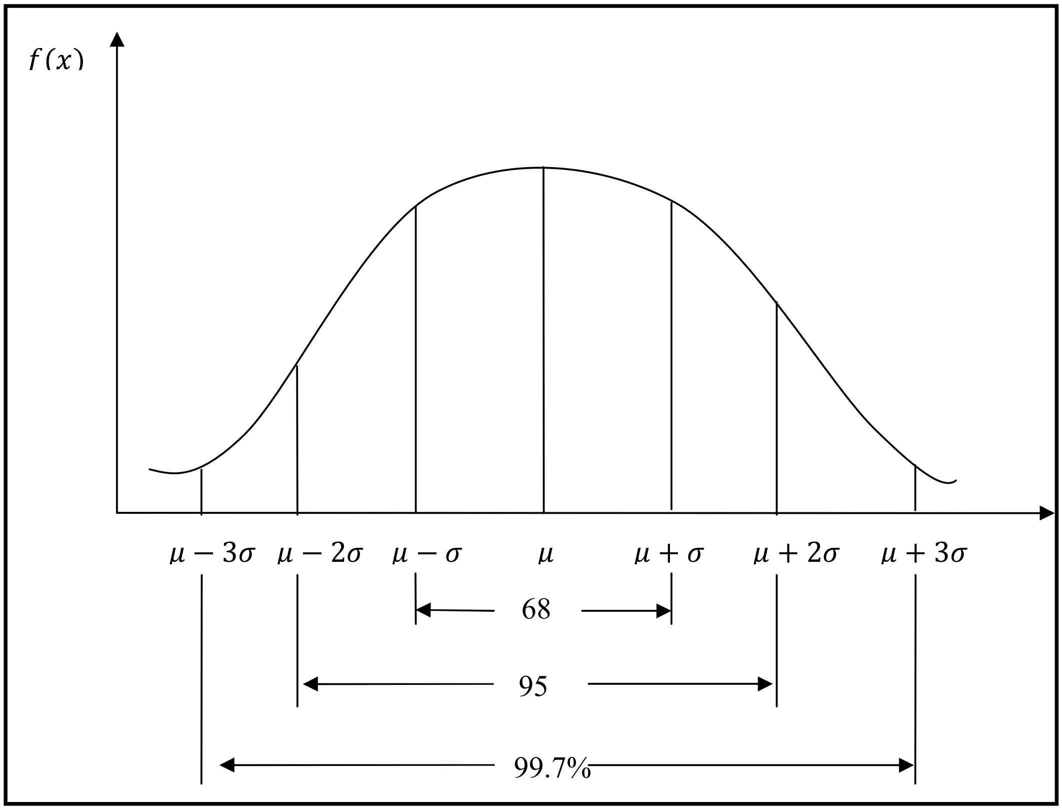

Figure 2.1 Probabilities associated with normal distribution. (Montomery & Runger ,2003)

Where P(.) denotes the probability that x lies within the indicated range. A graphical interpretation of these expressions is shown in Figure 2.1 where each probability corresponds to an area under the $f(x)$ curve. Equation 2.3 and Figure 2.1 show that if a random variable x is normally distributed there is a very high probability (0.9973) that a measurement lies within 3σ of the mean μ. This important result provides the theoretical basis for widely used SPC techniques

2.5 Control Chart

A primary tool used for SPC is the control chart, a graphical representation of certain descriptive statistics for specific quantitative measurements of the manufacturing process. These descriptive statistics are displayed in the control chart in comparison to their "in-control" sampling distributions. The comparison detects any unusual variation in the manufacturing process, which could indicate a problem within the process. Several different descriptive statistics can be used in control charts and there are several different types of control charts that can test for different causes in order to achieve the desired specificity. Control charts are also used with product measurements to analyze process capability and for continuous process improvement efforts.

2.5.1 The S-Chart

The main purpose of s chart is to determine whether the distribution for the process characteristic is stable or not. The s chart is an alternative to the R chart. Both of it have the same purpose: to estimate the process standard deviation and to determine whether it is in control. It seems more natural to estimate the process standard deviation with the sample standard deviation s than with the range R. In fact, when the population is normal, s is more precise estimate of the process standard deviation than is R, because it has a smaller uncertainty. Besides that, the computation of s involves all the measurements in each sample, while the computation of R involves only two measurements (the largest and the smallest). It turns out that the improvement in precision obtains with s as opposed to R increase as the sample size increases. It follow that the s chart is better choice, especially for larger sample sizes (greater than 5 or so).

2.5.2 The R Chart

This chart controls the process variability since the sample range is related to the process standard deviation. The center line of the R chart is the average range. The R chart is normally used for numerical data that is captured in subgroups in some logical manner for example 3 production parts measured every hour. A special cause such as a broken tool will then show up as an abnormal pattern of points on the chart.